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DESIGN OF FLEXIBLE ELECTRICAL CAPACITANCE TOMOGRAPHY SENSOR

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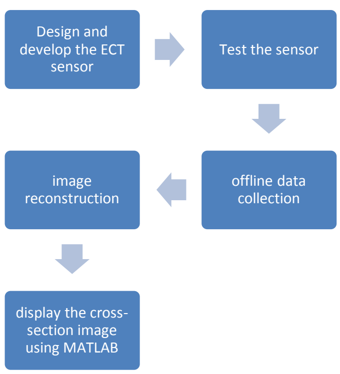
Graphical abstract



Abstract

This paper discussed the design–functionality and application of Flexible Electrical Capacitance Tomography sensor (FlexiECT). The sensors consist of 12 electrodes allocated surrounding the outer layer of the pipeline. The sensor is designed in such that the flexibility features suit the applications in the pipeline of multiple size. This paper also discussed the preliminary result of FlexiECT applications in fluid imaging by identifying the percentage of two mixing fluids.

Keywords: Electrical capacitance tomography, tomogram imaging, distribution of fluid

Abstrak

Kertas kerja ini membincangkan rekabentuk–fungsi dan aplikasi pengesan tomografi Elektrik Kapasitan fleksibel (FlexiECT). Pengesan ini terdiri daripada 12 elektrod yang diperuntukan di sekeliling lapisan luar saluran paip. Sensor ini direkabentuk sedemikian dengan ciri yang fleksible untuk disesuaikan dengan aplikasi saluran paip yang berbilang saiz. Kertas kerja ini juga membincangkan hasil awal aplikasi FlexiECT dalam pengimejan cecair dengan mengenalpasti peratusan pencampuran dua cecair.

Kata kunci: Tomografi elektrik kapasitan, pengimejan tomogram, pengagihan cecair

1.0 INTRODUCTION

Electrical Capacitance Tomography (ECT) Sensor is widely use in process control for monitoring and control the quality of an industrial process. As one of non-destructive testing, it can be used to detect any of fluid without interrupt the whole process. By reviewing the cross-sectional image from this sensor, the contaminations of the fluid or liquid can be determined. Conventionally, most of the ECT sensors were designed with fixed size to suit the application to certain size of pipes. Elmy Johana and team [1] did design a portable types of ECT, but the specification was still in fixed type. This project proposed a new design with flexible capability which can suit the applications on any pipe sizes.

2.0 SENSORS DESIGN CRITERIA

Basically, there are two ways to develop the ECT sensors either using internal or outer electrode. The electric field is proportional to the permittivity of the material as a higher permittivity material introduces inside the region of interest. Meanwhile, for external electrode, the capacitance may increase or decrease depending on the thickness and permittivity of the wall and its content because the permittivity of the wall causes non-linear change in capacitance.

At the early stage, the selection of number of electrodes is most important. The data acquisition is less complex if the number of electrodes is small. Less number of electrodes may lead to faster data acquisition rate however the image obtained is low in quality [1], [2]. By increase the number of electrode, the resolution of the image can be increase but the processing speed will reduced. To maintain the high speed, more complex system has to be developed and normally this will associated with increasing of cost.

Another criteria need to be consider is wall thickness. The sensitivity of the distribution fluid inside the pipe bore can be influenced by wall thickness because it has negative effect on the measurement of internal capacitance. When medium capacitance is too small compared to the wall reactance, it became more difficult to resolve the internal capacitance from the measurement capacitance value. So by using thinner wall, the better sensor performance can be achieved [3].

Cover angle of the electrodes also play the important role on the criteria selection. By increasing the cover angle of the electrodes, the length of the electrodes will be reduced. These electrodes then need to be guarded by earthed screens and earthed axial end screens to reduce and prevent interference of external noise due to negative effect on capacitance measurement.

Taking into account all the above mentioned issues, the Flexi-ECT sensor is designed using 12 electrodes allocated around the pipeline. In order to preventing the electric field lines from spreading axially at the ends of the measuring electrodes, the electrode guard is designed as shown in Figure 1. Normally there have two types of guards; axial guard and driven guard.

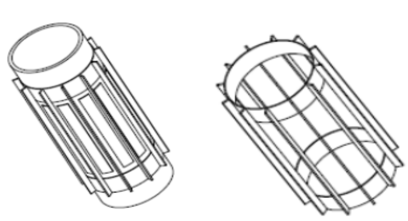


Figure 1 Design of sensor guard

The axial guard holder is design to hold the axial plate and driven guards are placed inside the axial guard holder. All guards will be grounded to make them at same potential condition. The outer screen is made of PCB to shield the electrodes and it was grounded together with the axial screen.

To make the flexible ECT sensor available and easy for for pick and place process, the electrodes are mounted together with outer screen. PCB stand are used to hold the electrode and outer screen but separated by insulating material as shown in Figure 2. Thickness of the insulating material will affect the capacitance reading and influence the measurement distribution and characteristic of the ECT sensor [6]. To minimize the stray capacitance due to cable movement, temperature changes and component variation and etc, the transmitter and receiving circuit is connected directly to the sensor using connector. The sine wave with 500 kHz, 20 Vp-p is injected to the circuit because at this excitation signal, the circuit has good linearity and stability [1], [7].

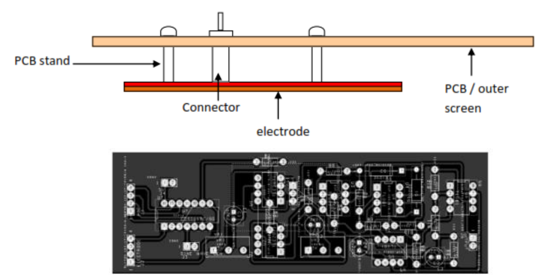


Figure 2 Electrode mounted together with guard and receiving circuit

All the receiving circuits are plug on to the ECT sensor in order to testing the hardware as shown in Figure 3.

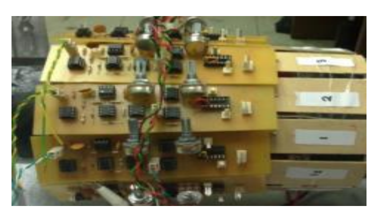


Figure 3 Sensor under testing process

In any application of an ECT hardware system, the calibration must be done before it can be used to find loss value of the projection. Each of sensitivity matrix is then multiplied by its corresponding sensor reading to construct the image [5]. In order to find the voltage distribution inside the pipeline, following equation can be applied:

$$V_{LBP} = \sum_{T_x}^{n}\sum_{R_x}^{n} s_{Tx,Rx} \text{ x } \overline{M}_{Tx,Rx}(x,y) \quad (1)$$

where, sensor loss value for Tx-th and Rx-th projection is remark as $S_{TX,\ RX}$. While reference voltage value for Tx-th and Rx-th projection is denoted as Vref $_{TX,\ RX}$ and measured sensor voltage value for Tx-th and Rx-th projection as $V_{TX,\ RX}$.

Because of the mixture fluid presented in voltages or state, the normalization of the value needs to be done. This normalized inter-electrode capacitance can be defined as the following equation:

$$C_N = \frac{C_M - C_L}{C_H - C_L} \quad (2)$$

where C_N is the normalized capacitances, C_M is the absolute capacitances set, measured with the sensor containing a material of arbitrary permittivity, C_H is the capacitances measured set at the higher permittivity calibration point (fluid 2) and C_L is the capacitances measured set at the lower permittivity calibration point (fluid 1).

To identify the C_x value, there are several parameter need to be considered. Output voltage V_o in the equation of C_x will becomes V_M *(maximum voltage)* for voltages measured at different distribution of mixture fluid, and V_H *(high Voltage)* when pipe filled with higher dielectric permittivity material and V_L *(low voltage)* measured when pipe filled with lower dielectric permittivity material. C_x value can be identified by the following equation:

$$C_x = -\frac{AV_o}{j_\omega R_f V_i} \quad (3)$$

This corresponding unknown capacitance C_x remarked as C_M, C_H and C_L respectively. The capacitance equation are becomes as follows

$$C_M = -\frac{AV_M}{j_\omega R_f V_i} \quad (4)$$

$$C_H = -\frac{AV_H}{j_\omega R_f V_i} \quad (5)$$

$$C_L = -\frac{AV_L}{j_\omega R_f V_i} \quad (6)$$

Substitute all capacitance equation inside the Normalize capacitance formula. Thus the normalize process are simplifies the image reconstruction process by calculating the measured voltages only for a given formula.

$$C_N = \frac{V_M - V_L}{V_H - V_L} \quad (7)$$

From this normalize capacitance equation, we can find the sensor loss as follows,

$$S_{Tx,Rx} = \frac{V_{max} - V_{in}}{V_{max} - V_{min}} \quad (8)$$

The sensor loss can be obtained by computed the measurement value in the formula $S_{TX,RX}$. This sensor loss value then will multiplied with sensitivity matrix in order to get distribution of voltage of LBP.

3.0 RESULTS AND DISCUSSION

The experiment has been conducted to evaluate the performance of sensor by investigate the distribution of fluids inside the pipeline and reconstructs the cross-section image using MATLAB.

In Figure 4, signal 1 shows the raw signal received by detection electrode. The value of this signal is too small with approximately of 114mVp-p and contained noise. This signal then was injected to the AC capacitance measuring circuit, whereas signal 2 shows the output result from AC capacitance measuring circuit without any existance of noise and the signal has been amplified to 7.6Vp-p.

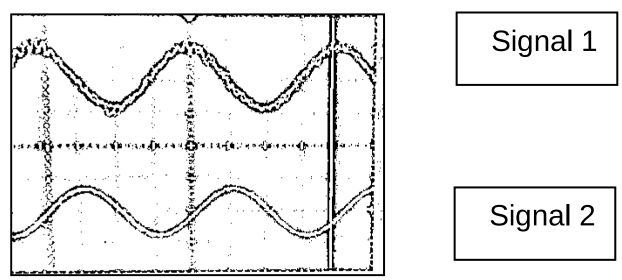
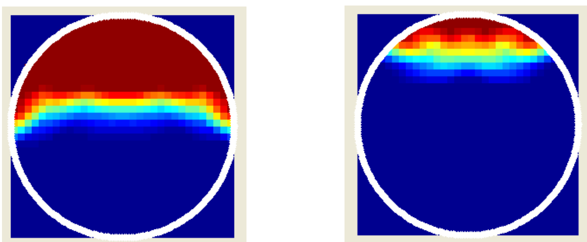


Figure 4 Output signal from detection electrode (signal 1) and AC capacitance measuring circuit (signal 2)

The data is summarized in Table 1. This table shows the voltage recorded for electrode 1 acts as an excitation electrode. The highest voltage value is recorded if electrode closed to excitation electrode. As distance goes far from excitation electrode, the voltage values drops due to large coverage pf detection area. So from this result, the sensitivity of the ECT system becomes less if the gap between these two parts is large.

The sensitivity for the measured properties is not constant within the region of interest. Measured voltages can be either more than higher permittivity calibration voltages or less than lower permittivity calibration voltages. These normalized voltages then used to reconstruct images using Linear Back Projection (LBP) algorithm through MATLAB. Figure 5 shows the simulation of the cross-section image of mixing fluid inside the pipeline. The permittivity distribution level is conventionally show by the RGB color where red represents higher permittivity area, cyan and yellow is intermediate permittivity distribution while blue represented the lower permittivity. Therefore from this two cross-section image, the fluid with lower permittivity will float on the top of the fluid with higher permittivity. Then there have intermediate condition (yellow area) due to frequent mixing of both fluids.



50% fluid 1 and 50% fluid 2 20% fluid 1 and 80% fluid 2

Figure 5 Cross-section image of mixing fluids inside the pipeline

Table 1 Voltage recorded at detection electrodes with gapping 2 mm

Measurement No.	Source electrode	Detection electrode	Signal before AC circuit	
			Full air (mV)	Full water (mV)
1		2	140	108
2		3	22	30
3		4	10	22
4		5	12	28
5		6	6	14
6	1	7	8	20
7		8	52	86
8		9	36	52
9		10	68	88
10		11	72	56
11		12	76	68

4.0 CONCLUSION

The main objective of this project has been successfully achieved which means the system can be used to determine the distribution of fluid inside the pipeline and visualize it through GUI program using MATLAB. Although this project only experimented to verify the idea of sensor design, it also can show the representation of real process of the system from this experimental result as shown in section 3. Because of the testing have been done in offline system, the real time distribution has not been tested yet. Next, the focus will more on the identification of mixing fluid and solid material in order to maintain the purity of the material.

Acknowledgement

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References

[1] Johana, E. 2011. Electronic Design for Portable Electrical Capacitance Sensor: A Multiphase Flow Measurement. *4th International Conference on Mechatronics (ICOM)*.

[2] Yan Li. 2007. The Study on Image Data Acquisition System for Electrical Capacitance Tomography System. *IEEE Conference on Industrial Electronics and Applications*.

[3] Wuqiang Yang. 2010. Topical Review: Design of Electrical Capacitance Tomography Sensors. *Measurement, Science and Technology*. 21(042001): 13.

[4] Huang, S. M. 1992. Design of Sensor Electronics for Electrical Capacitance Tomography. *IEEE PROCEEDINGS–G*. 1992. 139(1).

[5] Ruzairi Abdul Rahim. 2011. *Optical Tomography: Principles, Techniques and Applications*. First Edition. Penerbit UTM Press. 7-9.

[6] Kjell Joar Alme and Saba Mylvaganam. 2006. Electrical Capacitance Tomography-Sensor Models, Design, Simulation and Experimental Verification. *IEEE Sensor Journal*. 6.

[7] Chan Kok Seong. 2008. Electrical Capacitance Tomography (ECT) System with Mobile Sensor for the Liquid Measurement. Thesis. Universiti Teknologi Malaysia, Malaysia.

[8] Williams, R. A. and Beck, M. S. 1995. *Process Tomography: Principles, Techniques and Applications, Image Reconctruction*. 281-295.